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ABSTRACT

Even without relying on individual student testing there is a great deal that teachers can know about student learning in their classrooms. The purpose of this article is to ask: As a means of identifying student learning, what alternatives to testing exist within normal classroom practices? First the context of the work reported here is described in order to explain the impetus for the question asked. An analysis of the different kinds of things that can provide information on student learning in normal classrooms is presented. The analysis is illustrated with two examples drawn from Project DISTIL which is a study of experienced high school science teachers. The conclusions to the above question are summarized. (PR)

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WHERE'S THE STUDENT IN PROJECT DISTIL?

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Introduction

The need to take account of students' conceptions of the natural world in the teaching of science has received increasingly wide acceptance over the past 15 years. As a result an important question for teachers is: How do I know where my students are, intellectually and conceptually speaking? This has led researchers and teachers to employ a number of different techniques that use both verbal and written feedback from individual students in order to elicit the content, structure, and context of students' conceptions. Researchers have found open-ended interview techniques essential to discover the complex and detailed nature of these conceptions. Teachers, on the other hand, have increasingly come to use instruments with written feedback and limited options for pragmatic reasons: they need the information immediately. So individual student testing, ubiquitously used for assessing learning and grading students, has come to be used in a new role: that of eliciting student conceptions. The familiarity of these procedures appears to have made the transition a relatively easy one for many teachers.

There is thus likely to be wide support for the view that by using individual student testing teachers can determine what conceptions students hold and, more generally, what student learning has occurred in their classrooms. With the ready availability of testing there has been no great need to examine corollary propositions too closely. It nevertheless seems likely that many people would find it reasonable to assert that without individual student testing, teachers cannot determine what student learning has occurred in their classrooms. For reasons outlined below, we have reconsidered this proposition and come to a different conclusion: even without relying on individual student testing there is a great deal that teachers can know about student learning in their classrooms.

The purpose of this article, then, is to ask: As a means of identifying student learning, what alternatives to testing exist within normal classroom practices? First we describe the context of the work reported here in order to explain the impetus for the question we have asked. Then we present our analysis of the different kinds of things that can provide information on student learning in normal classrooms. Next we illustrate our analysis with two examples drawn from Project DISTIL: a study of experienced high school science teachers. Finally we summarize our conclusions to the question posed above.

The context: Project DISTIL

The impetus to consider whether classroom practices other than student testing could be used for assessing student learning arose from within Project DISTIL (Hewson & Hollon, 1989).[1] Central to Project DISTIL is the idea that the thoughts teachers have about the content and students they are to teach influence the way in which they will teach. The goal of the project was to explore this idea by investigating relationships between teachers' conceptions of teaching science, their knowledge-in-action as represented in their classroom practice, and the conceptual learning of their students. The teachers studied were experienced high school biology, chemistry, and physics teachers who taught the same three content topics in their respective disciplines.

The initial proposal was to track students' conceptual learning by using written student tests to be developed in nine content areas (3 in each discipline) and administered to the students before and after instruction. After a pilot study revealed a number of problems with student testing, a decision was made to eliminate student testing from the project. The present article is a direct outgrowth of this decision.

Several reasons contributed to the decision to drop testing from the project. The major one was the enormous amount of time required to develop coding systems for nine student tests each containing 10 to 15 items, given the complexity, "open-endedness", and conceptual goals of the test items. Other reasons related to test administration (teachers were reluctant to give up class time; students lacked motivation to take tests seriously) and the possibility of mismatch between our goals and those of the teachers.

As we became aware of the problems associated with student testing in the project, the need to consider alternatives arose. A consultant to the project (Charles W. Anderson) had suggested that general characteristics of student learning could be inferred through observation of the tasks students were required to complete during a unit. After some investigation we became convinced that this might be a viable alternative and made the decision to drop student testing from the project. In time, as we investigated this and other possibilities, the question posed at the outset of this article crystallized: As a means of identifying student learning, what alternatives to testing exist within normal classroom practices?

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[1]The acronym stands for Description and Interpretation of Science Teaching with Implications for Learning.

Teacher knowledge

This section summarizes two central issues in Project DISTIL--teachers' conceptions of teaching science and knowledge-in-action--and the methods used to determine them. Data gathered and analyzed in these ways are presented later in this article.

In the project we have adopted a constructivist point of view, arguing that teachers build conceptual structures in which they incorporate classroom events, instructional concepts, socially approved behaviors, and explanatory patterns. We have distinguished between two aspects of a teacher's knowledge. On one hand, there is the general, formalized propositional knowledge that a person may possess (Schön, 1987, p. 40). In the present study we see this knowledge as including the set of ideas, understandings, and interpretations of experience concerning the nature and content of science, the nature of learners and learning, and the nature of instruction and teaching that the teacher uses in thinking about teaching science. We describe this as a science teacher's conception of teaching science (Hewson & Hewson, 1989).

On the other hand, there is a teacher's knowledge-in-action: that form of knowing inherent in a teacher's actions in the context of daily teaching activities (Schön, 1983, 1987). Knowledge-in-action is partly conscious and partly implicit in actions, and may be accessible through reflection on particular events. We do not view knowledge-in-action as synonymous with a conception of teaching science; for example, it is highly contextualized and partly implicit. The relationship between a teacher's conception of teaching science and knowledge-in-action remains, however, an open question.

The conceptions of teaching science held by experienced teachers were determined using an interview task developed by Hewson & Hewson (1989). The task was designed to enable respondents to consider the components of an appropriate conception of teaching science, while providing an environment in which a variety of views could be expressed without being biased by the structure of the task. It was developed to allow subjects to respond to typical classroom events while encouraging them to link the events to larger conceptual issues.

The conduct and analysis of each individual's interview has been described in detail elsewhere (Hewson, et al., 1992). The analysis produced a set of about 15-25 statements summarizing each teacher's ideas with respect to four categories: the nature of science, learners and learning, rationale for desired instruction, and the teaching of science. These summary statements were grouped, where possible, into themes that were defined as an idea that recurred in two or more of the four categories, and provided an overview of the interviewee's conception of teaching science.

The knowledge-in-action of the participant teachers was determined by combining data obtained from intensive observation and multiple interviews. First, the observations of a teacher's classroom during the teaching of relatively self-contained topics described each topic as enacted by the teacher and experienced by the students. Second, post-topic interviews (or PTI), designed to probe the reasoning behind instructional decisions made while teaching the topic, were conducted after each of three topic observations. These observations and interviews helped us to develop insights into the practice of experienced high school science teachers in developing and carrying out instruction. In other words, the combined analysis of observations and post-topic interviews provides a representation of the teacher's knowledge-in-action.

The observations of a teacher's lessons were recorded in writing and on videotape. The data collected on a daily basis thus for the most part included written observation notes, a written summary of the lesson, written comments made by the observer of particularly interesting features in the lesson, the videotape of the lesson, and the coding of the observation for modes of instruction, levels of discourse, cognitive demand of students, and content development.

The post-topic interview (or PTI), conducted with each teacher after each topic, was constructed around representative and significant events that had occurred in the teaching of the topic in order to understand why the teacher taught as he or she did. We found that the PTI was very useful in gaining insights into a teacher's rationale for instruction and his/her basis for making reasoned decisions.

An outline of alternatives

We have identified three different ways of thinking about the question of identifying student learning without using individual student testing. The first is to focus on direct evidence of student learning available from classroom activities other than students' written tests. The second is to identify the possibilities for student learning inherent in the classroom activities that embody the details of a teacher's practice. The third is to examine the influence that teachers' conceptions of, and beliefs about, science, learning, and teaching have on their choice of and response to classroom activities.

Direct Evidence

Students provide direct evidence of what they know and what they have learned in several different forms: written, spoken, and enacted. Nevertheless, while any form of feedback from students has the potential to provide evidence of learning, it needs to be recognized that not all forms are equally valuable or accessible.

With respect to written forms of evidence, apart from tests, quizzes, examinations, etc., there are a number of classroom activities that require students to write. Some examples of these are completing worksheets, writing out problem solutions, and writing up laboratory reports.

Students provide evidence of learning in spoken form in different ways: in answering questions posed by teachers, in asking questions, or in contributing to discussion whether in the whole classroom or in small groups doing seat work or lab work. Students also can provide evidence of their state of learning through their actions. Some examples of these might be drawing diagrams, performing experimental work, or role playing in acting out a model. A student's general demeanor of confidence or insecurity can also provide valuable clues to a teacher.

There are, of course, several characteristics that have led to a preference for individual testing over other sources of evidence. One of these is testing's specificity: a particular question can be directed at a specific item of information, requiring less interpretation on the part of the teacher. Another is its completeness: it provides information on each student in the class. A third is its uniformity: the same question is asked of each student. These are characteristics that have largely been used to support claims of fairness, an essential ingredient in any credible system of grading. Where one is more interested in a general sense of where students are, however, these advantages in favor of individual testing become less important.

Opportunity and constraint

There are components of a classroom that allow one to make predictions about the student learning that is or is not likely to occur there. These include the tasks students are required to complete during a topic and the tools teachers make available to their students. One way of thinking about the role of tasks set for students to do and tools for them to use is in terms of windows that teachers open in order to provide opportunities for their students to learn selected goals. In opening one or more chosen windows a teacher intends that his or her students will see a particular view of the conceptual terrain around them and gain a perspective on the scenery that is framed by this view.

Another way of thinking about the role of tasks and tools used by a teacher is in terms of constraints. Consider a horse's harness: a rider places harness, bridle, and saddle on a horse in order to ride. The harness serves to curb the horse's tendency to go in a variety of directions. In a classroom, a task has a specific purpose that focusses attention in a particular direction, thereby constraining a student from going in a variety of directions. To carry out the task successfully requires that not just any method be used: there is a constraint on acceptable methods.

Opportunities--opening windows--accentuate the positive since they provide access to and give perspective on a scene. On the other hand, constraints--using harnesses--have negative connotations:

a limitation of available options, a restriction of freedom, a curbing of opportunity. Yet such a dichotomous characterization is too simple. On one hand a constraint such as a horse's harness is often necessary in order to achieve a desired goal. Without the constraint the task would not have been accomplished in the manner expected. In other words, the constraint creates its own opportunities. On the other hand the opportunity that comes with opening a window has its own restrictions: the window frames (and thus limits) the view; also, other windows that might have been opened remain closed. In other words, the opportunity creates its own constraints. There is a paradoxical symmetry between the two; opportunity and constraint are two sides of the same coin.[2]

We believe it is valuable to think about tasks and tools both as windows and harnesses in order to accentuate their inseparably dual nature as opportunities for and constraints on student learning. In other words, we suggest that the tasks and tools used by a teacher can usefully be used as indicators both of what is and is not possible as an intended student learning outcome within that teacher's classroom.

In analyzing classroom tasks and tools to identify the role that they might play in providing evidence of student learning, it is important to note two ways in which this might happen. The first relates to their ability to provide information, of whatever kind, about student learning, i.e., there is a need to recognize that some tasks or tools, e.g., asking students questions, are more likely to lead to students' providing direct evidence of their knowledge than others, e.g., giving students a lecture. The second relates to the opportunities and constraints inherent in a task or tool, i.e., we need to recognize that some tasks and tools require much more of a student than do others. For example it is more demanding to ask a student to analyze an unknown event than to ask them to recall a piece of information.

Classroom tasks. We have worked to develop descriptions of the general characteristics and opportunities for student learning by considering the cognitive demand of tasks that students were held accountable for completing (both in class and out of class) (Brophy & Alleman, 1990; Doyle, 1986).

While this approach provides, at best, an estimate of the possibilities, it does serve to illustrate the upper and lower limits on expectations. Our rationale is as follows: in some classrooms, there exist many open-ended, independent projects where students are expected to analyze a situation, develop a solution possibility, and test the solution. In other classrooms, students are held accountable for

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[2]We recognize that the metaphors of window and harness raise a number of questions, e.g., what input might students have in choosing learning outcomes that are seen to be desirable? We will not, however, discuss them further, not because we regard them as unimportant or lacking interest--on the contrary--but because our focus in this article is elsewhere.

completing convergent questions that require a search for some correct answer, the application of a known rule, or solving of type problems. They are rarely asked to explain an idea or defend a position. In the first case, some students may not learn to accomplish those open-ended activities very well; there are many mitigating factors that might prevent their being successful. However, the opportunity and potential for that learning is evident in the learning environment. In the second case, though, it is unlikely that many students would learn to analyze problems and develop potential solutions because there are no opportunities for those skills to be practiced, nor is there any explicit message within the classroom environment that suggests that such activity is valued or expected. We recognize one significant limitation in this approach: there are a variety of differences between the demand of a task as described in a printed handout and the task as actually completed by a student. Our analyses of instruction have attempted to maintain sensitivity to this transformation of student tasks.

Tools. One type of resource that teachers make available to their students is a tool: something that makes a difficult task simple, amplifies the power available to tackle a task, allows a task to be accomplished that without the tool was impossible. Physical tools are well known: hammers, screwdrivers, wrenches are just the start of a lengthy list. Computer software such as word processors, databases, and spreadsheets have been termed productivity tools for their ability to transform writing, sorting, and calculating tasks, among many others. In science labs, measuring instruments such as rulers, scales, clocks, etc. (and their modern manifestations) are tools that have been crucial in the development of all disciplines. Perhaps more important than any other, though, are conceptual tools: ways of thinking that have solved seemingly insoluble problems. The differential calculus as a means of handling variable, correlated change is a superb example of the power of a tool to transform a problem. There are many other mathematical tools: algebra, geometry, statistics, etc. Language, too, provides us with a wide variety of conceptual tools for understanding: metaphorically, concepts are spectacles that allow us to see clearly what was previously an undifferentiated blur.[3]

There is value, in our opinion, in using the notion of tools to think about the question we have raised in this article. In a hypothetical example of two classrooms identical in curriculum and instruction except for the provision of graphs for plotting experimental data, say, there seems little doubt that students in the graph classroom would have a distinct advantage over the others in coming to understand the nature of the relationship between two important quantities. In other words, including tools with tasks in the analysis of opportunities for and constraints on learning within a particular classroom seems to us to make sense. In doing so, there is at least one caveat: we do not

[3]The boundaries between these categories of tools are vague and not exclusive; in how many categories could a microcomputer based laboratory be at least partially placed?

regard tools as automatically desirable. When a tool makes a challenging task mundane and mechanical, it is possible that the task may lose its purpose. There is also the danger that the tool may itself seem to replace the phenomenon of interest, perhaps by getting in the way and obscuring it.

Teachers' conceptions

Central to Project DISTIL is the idea that teachers' thinking influences their practice. At the present time this may seem to be a truism, yet as recently as 20 years ago the dominant paradigm focused entirely on teacher's observable behaviors, treating these as skills that people could be trained to perform. Since that time, however, the study of teachers' thinking and the relationships between thought and action has become a major research issue (Calderhead, 1987; Clark & Peterson, 1986; Kagan, 1990; Pajares, 1992).

Research has shown that science teachers possess different views about the nature of science, of learning, and of teaching (Aguirre, Haggerty, & Linder, 1990; Lederman, 1992) and that these views are related to their classroom practices (Brickhouse, 1990; Duschl & Wright, 1989; Gess-Newsome & Lederman, 1992; Lederman & Zeidler, 1987; Lyons & Freitag, 1993). For example a teacher who believes it is necessary for students to know a large vocabulary of terms as a knowledge base for studying biology is likely to include tasks that require rote memorization, quite possibly with tools such as mnemonics to help students remember. Alternatively, a teacher whose view is that rote memorization is a waste of time is likely to introduce tasks that do not depend on it, such as open-book examinations. In other words, a teacher's conception of teaching science potentially has a significant influence on the choices of tasks and tools he or she uses, and thus on the opportunity for learning available to students in that classroom. After analyzing a teacher's conceptions of teaching science we have found, for the most part, that we can predict with some accuracy the type of teaching we would see in that teacher's classroom.

Illustrations from the classroom

We shall illustrate the three different ways of identifying student learning discussed above by using two teachers whom we studied in Project DISTIL. Because our analyses have shown us that it is critical to consider all aspects of the context of a classroom in interpreting what teachers do, we have chosen to focus at some length on two teachers rather than to present isolated tasks from many teachers. It is important, however, to note that our prime focus is on ways of identifying student learning and not on the teachers *per se*: the pictures that emerge are not intended to be complete, balanced critiques of these teachers.

Ms. Sorenson[4]

Ms. Sorenson teaches high school physics. We interviewed her using the CTS interview, observed her teaching two topics--Newton's second law and energy--and interviewed her at the conclusion of each topic. In the teaching we observed Ms. Sorenson emphasized conceptual development rather than problem solving, her focus in previous years. Below, we describe some of the classroom and laboratory tasks she used in her instruction, in each case discussing the potential for student expression inherent in, and the potential cognitive demand of, these tasks. We also summarize her expectations of science teaching derived from the CTS and post-topic interviews, and discuss how this might influence interpretations of the tasks she used.

Classroom Tasks. Ms. Sorenson frequently used tasks that encouraged her students to present their ideas on an issue before it was dealt with in class. Consider the following task she set for her students:

> T: Tomorrow I want to start on statics, and here's something I want you to think about. And I don't want you to answer me yet, and I don't want you to read your textbook. Because here's my question. (puts book on desk) The book's laying on the table. Don't answer this question until tomorrow. How many forces are acting on it? Don't answer this question until tomorrow. Don't look it up. I just want to know tomorrow your first idea, whatever popped into your head when I asked you how many forces are acting on this book....I need to know your initial reaction. (N2 d2)

The next day, she led a discussion:

> T: Now that we're caught up to where we left off yesterday, let's talk about the book sitting on the table. (students comment) That's enough, you guys. At least you're alive today. Mike. Mike, how many forces are acting on this book?
> Mike: (pauses) One.
> T: One. The force of what?
> Mike: Gravity.
> T: Gravity. Just wait. How many of you agree with Mike here? (one student agrees) Well Rudy what do you say if you don't agree with him?
> Rudy: (two forces)
> T: OK, what are they?
> Rudy: Gravity and .....(hesitates)
> T: Well describe them. If you don't have a name for it, describe it.
> Rudy: .....otherwise it would be moving.
> T: Norm, did you hear what Rudy said? He said there's some force pushing that book up. Does that make sense to you?
> Norm: (inaudible)
> (T asks another student who replies.)
> T: Yeah, he read the book. I asked him not to, doggone it.
> (T asks other students.)

[4]Teachers' and students' names have been changed.

T: Rudy said something extremely important besides the fact that it's weight and some other force pushing up. He said that if it were only weight - this is extremely important - if it were only weight, the force of gravity, weight, acting on that book, it would have to be moving. Right? (N2 d3)

The transcript shows that Ms. Sorenson listened carefully to students and used Rudy's response as a basis for her subsequent comments. While in this case her content preference was clear, on other occasions she would support a student's right to disagree. "Kira, you can agree to disagree." (EN d2) Neither did she want students to agree with her if they really didn't:

T: (has explained a friction example) Does that make sense to you, Norm? Ray? Yes or no really? Doug? I mean, are you believing it because I say it, or are you believing it because you know what I'm talking about?
Doug: Believe it. (N2 d4)

A similar example of exploring students' thoughts occurred at the outset of a lab in which she was preparing students for an activity in which they were to pull a spool of thread horizontally with the thread coming from the top and the bottom of the spool:

T: Which way is the spool going to go? (student answers) Think so, huh? How about the rest of you?
Kira: They're both going to go back.
T: They're both going to go back, Kira says. That's her hypothesis. What do you think, Dawn?
Dawn: (inaudible)
T: Dawn says when you pull it from underneath, it's going to roll away from you. When you pull it from the top, it's going to roll toward you. Ivan?
Ivan: (questions whether it will roll in either case.) (N2 d3)

The tasks illustrated above were typical of much of Ms. Sorenson's practice. They were open ended, thus encouraging a variety of responses from the students. The way in which she followed up student responses reiterates the same point. She preferred to deal with their initial thoughts rather than giving them information to digest. She actively encouraged students to state their own ideas, she accepted them for the most part at face value, and on occasions asked students to explore why they held them. In other words, the tasks created the opportunity for students' own thinking to become explicit. There is, however, some vagueness with respect to the potential cognitive demand of these tasks. For the most part, there isn't any follow up on a response: the student states it, the teacher accepts it without comment, and moves on; the response could be based on anything from a random guess to a deeply thought out answer. Without explicit statements, modelling, etc., that high cognitive demand is required, students would, in our view, be more likely to opt for a simpler approach.[5]

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[5]While the question of what a teacher in general, and Ms. Sorenson in particular, does with information on students' thoughts is obviously important, it is not central to the topic of this article and will not be discussed further.

Laboratory Tasks. Ms. Sorenson's labs were of two types. The first involved discovery activities (such as the one just mentioned) in which students investigated presumably novel effects. The task was to observe, perhaps be surprised, but to trust the observations. From the spool of thread lab:

T: What's happening?
S: It's going the wrong way.
T: (laughing) No, it's not! (N2 d3)

Even though she had spent time eliciting students' thoughts, once the observation had contradicted the student's expectation, Ms. Sorenson's preference for the empirical result was immediate and obvious.

The second type of lab focused on students' making measurements and doing calculations to illustrate principles already introduced. The students' task was presented very differently. For example, to introduce a lab (Making the Grade) in the energy topic, Ms. Sorenson handed out a sheet of instructions, pointed out the equipment, and told the students to read the lab for homework. Next day, students started the lab without more ado. For the most part, Ms. Sorenson let them struggle and sort out their problems on their own. She did not discuss the results in class at all.

These two types of lab task are very different, in terms of both the opportunities for students providing evidence of their learning, and the potential cognitive demand of the tasks. The discovery lab was one in which students were encouraged to express different possibilities. The question was: What could happen here? This could allow students to check their predictions, hypothesize, investigate relevant parameters, develop explanations, etc. In sum, the task provided many opportunities for students to express their personal ideas and the potential cognitive demand was high. On the other hand, the cook-book lab required students to follow instructions and produce results that had been planned in advance and could be checked for correctness and accuracy. Here the question was: Is it right? The task demanded that students apply previous knowledge in a carefully constrained situation. In other words, students were likely to reveal very little of themselves and the potential cognitive demand of the task had upper limits.

Conceptions. The analysis of Ms. Sorenson's CTS interview showed that her conception of science teaching is strongly characterized by two major components: the value of hands-on physical experiences and discovery as a major link between science and learning. These are contained within three closely interwoven themes that are centered on her view of learning: how it happens, what it is and how it is used.

Sorenson's first theme is: **science and learning both occur through the process of discovery.** Science, and physics in particular, involves making observations, asking questions, coming up with and

testing theories; this for her is the process of discovery. She also sees that these activities are what students do when they learn by discovering things for themselves. In instruction Sorenson expects to use techniques that involve students actively, because for her they initiate discovery learning.

The second theme is: **hands-on, concrete manipulations of physical objects are essential to learning science.** In her eyes, science teaching lends itself to hands-on experiments, demonstrations, and manipulating equipment. While these are important in helping students discover things on their own, they are also valuable because, for her, high school students learn better if they do something physical. Sorenson sees that such students, like her, are "pretty much concrete".

The third theme--**useful learning involves ingestion**--is central to Sorenson's view of how knowledge is acquired and used. For her, when a student "ingests" useful information, he or she takes it in, incorporates it with other information, and makes it so much a part of him/herself that s/he can apply it in different situations. She sees ingestion in contrast to memorization, a poor type of learning that doesn't last long and can't be applied.

The strong relationship that Sorenson sees between learning by discovery, the processes of science, and hands-on concrete experience is worthy of note because it relates so closely to her preferred instructional strategies. Here she sees a need for hands-on, concrete experience to assist the processes of learning.

The above themes arose as Sorenson talked about events unrelated to her own classroom. She reiterated similar themes, however, in talking about her classroom in her two post-topic interviews. At one point she spoke about the importance for her of students' doing laboratory work:

> T: Any time that you can get kids discovering things, doing things hands-on, we all learn better by manipulating objects rather than reading about concepts and watch them being written up on the board. Any time you can manipulate something and get some data from it, I think then you are learning much better, it's learning by doing, OK. I think that works much better than learning by reading and learning by writing things down. (PTI N2 291)

She also talked specifically about the second lab outlined above (Making the Grade):

> T: My point in this was what do you expect, in any lab, what do you expect to happen and what is actually happening. And the lab was successful in this way...when they took their first set of readings and they had it set up incorrectly...every lab group came to the conclusion they were doing something terribly wrong which means that they knew something about what should be going on. (PTI EN 563)

Discussion. Through Ms. Sorenson's eyes the classroom and laboratory tasks look slightly different than in the earlier discussion. There seems to be, in her view, some sense that the real world "speaks for itself" in an unambiguous way that defines what is right and wrong. Doing hands-on discovery labs should lead to a convergence of viewpoint. Even students, like Mike who have the

"wrong" idea should be able through observation and intellectual struggle to get to the right answer. While her actions do show it is important to her *that* her students express themselves, it appears that she downplays the importance of the *content* of what they say and why they say it. Thus the potential exists for identifying students' thoughts on a new concept, e.g., work, energy, and in a discovery-type lab, but it appears that she does not find a pressing need to use this information further.

The analysis of Ms. Sorenson's teaching demonstrates that her conceptions are related to the tasks she chose for her students and the ways in which she interpreted the feedback she received from them. In other words, knowing her views on science, learning, and teaching does provide a general indication of the type of learning that might be possible in her classroom.

Mr. Fielder

Mr. Fielder teaches high school chemistry. He was interviewed using the CTS interview, observed teaching three topics--stoichiometry, atomic structure, and acids and bases--and interviewed at the conclusion of each topic. Below, we describe a set of tasks he used in the teaching we observed and discuss the potential for student expression inherent in, and the potential cognitive demand of, these tasks. We also summarize his general views about teaching science derived from the CTS and post-topic interviews, and discuss how this might influence interpretations of the tasks he used.

Classroom tasks. A central part of Fielder's practice was a set of study tasks that he used with the purpose of helping his students organize their learning. On occasion Fielder referred to this set of tasks collectively as a system. He held students accountable for each of these tasks, these being for students to:

- prepare "an objective worksheet" prior to beginning each topic.

  This required students to read sections of the chapter. Each worksheet task asked students to define terms, recall facts, or paraphrase historical events presented in the text reading. This is illustrated in a sample of the objective worksheet drawn from the Atomic Structure topic:

  Having studied this chapter and done the problems, you should be able to:
  1. Define an atom.
  2. Summarize Dalton's atomic theory.
  3. Distinguish between protons, electrons, and neutrons in terms of their relative masses and charges.
  4. Discuss the structure of an atom including the location of the proton, electron, and neutron with respect to the nucleus.

- **answer questions orally from the worksheet at the start of the topic.**

  Fielder called on students systematically to check on their preparation, and elaborated, verified, or corrected the student's answer before moving on to the next question. He also entered a grade into his computer after each reply. An example of this highly structured discourse is:

  S: [The question was] "Summarize Dalton's atomic theory" (gives a brief summary)
  T. Excellent, this is a Dalton model. I guess the only thing I might add to that is in terms of the atoms, he thought of atoms as being the solid particles, in which case he didn't understand that there were subatomic particles. (ATS d1)

- **listen to a lecture.**

  Lectures generally took 1-2 full class periods and were dense with new and review material. Students were given lecture notes with corresponding textbook references and room to add their own notes. Demonstrations and models were an integral part of these lectures and served as examples, motivators, and occasions to broaden students' chemistry experiences.

- **solve problems.**

  Fielder generally started the problem sets during class by working several examples on the overhead. Students either worked problems in class or for homework. He did not circulate through the classroom while students worked but was available to answer specific student questions, one on one. After students completed the assignment, he asked them to share their work on the problems, again orally in class. They would also ask him to work problems on the overhead. Immediately after explaining each of his solutions Fielder quizzed the students on the problems and/or lecture material. This was a repeating pattern with lectures, problem solving, and short quizzes alternating until the topic material was covered.

- **carry out 1-2 lab activities, if time permitted.**

  The labs supplemented the material previously presented in the lectures and problems. The lab equipment was laid out and available to the students at their lab tables and they worked enthusiastically. There was much interaction between students during labs and occasional procedural questions for Mr. Fielder who circulated through the lab at its start and end.

- **complete an "issues worksheet."**

  This asked students to formulate opinions and extend their chemical knowledge into a real world context. These worksheets appeared toward the end of the topic and were not emphasized in class or on the tests.

  Fielder talked about his system on different occasions:

  T: I guess also in terms of the assignments, you get into a habit of reading, that's the first thing that happens. I try to give a little lecture, and discuss some of the main points in the reading assignments, and work in a few demonstrations. I also think for college

preparatory classes that problems are critical. I guess unless you sit down and do some of that you can listen to somebody tell you about it forever, it just isn't going to sink in. (PTI STO 803)

T: I spend quite a bit of time developing a scheme for interpreting information involved in problems and developing some tools that can be used in solving problems. Then we simply use those for the rest of the year. (PTI STO 1037)

T: I've always tried to have students learn in maybe three or four basic activities. One is reading and summarizing what they read. The second is to hear it or have it explained or have an opportunity to ask questions. And the third level is to see it happen in terms of demonstration or experience it in the laboratory. (PTI A&B 680)

Within Mr. Fielder's system there were several occasions when students' responses had the potential to provide direct evidence of students' ideas: these include Fielder's calling on students at the start of the topic and during problem solving, and in laboratory work. Yet he did not use these opportunities to follow up students' answers in order to understand why they answered as they did. Rather he used his system for several different purposes. First, he believed that the reading involved in preparing, say, the objective worksheets was a critical part of learning. As he commented:

T: I use those objective worksheets, in terms of reading and again it doesn't solve all your problems but I guess my feeling is that it is critical to do some reading and studying before you come to class. If you walk into class every day and you haven't looked at the book, a lot of it is going to go right over your head. I mean you just can't follow it. (PTI STO 580)

In other words, he saw the reading as preparing students for what was to come, to get them set, to provide a wake-up call. He held them accountable for this reading by requiring them to respond orally in class, grading their responses, immediately entering the grade into his computer, and basing 20% of their semester grade on in-class responses. Thus he provided a very clear indication of the importance he placed on students' prior reading, seeing this as a task to prepare students for what was to come rather than as a means of eliciting student understanding.

Second, Fielder would, for the most part, answer student responses with his own elaborations on particular points, rather than following up on the details of what a student had said. This was illustrated above; the segment below illustrates a rare follow-up question he asked before launching into his explanation. It occurred in a problem solving session:

T: Dell, number 4.
S: What is the pH of a solution whose hydroxide ion concentration is 1 x 10E-4 molar? (Explains how he worked the problem as T. writes on the overhead.)
T: Can you explain where this number came from?
S: Because the concentrations always add up to negative 14?
T: This actually is done before that calculation. The first thing he did was use that equation introduced in the reading assignment, which says that Kw is equal to . . . (Fielder continues an uninterrupted explanation for more than a minute before

concluding.] . . . then pH by definition is equal to the negative log of the hydrogen ion concentration, now note that the hydrogen ion concentration is 1 x 10E-10 power and if you take the log of 10E-10 you get what? (pauses, looks to the side)

S: Negative ten.

T: Negative ten. So the log of 10E-10 is negative ten and since it's the negative of the log, that means the pH is equal to 10. (A&B d1)

Finally, Fielder used one source of response--the quizzes--to help students keep track of their own progress toward achieving the stated objectives, rather than to provide him with any information on the content of their answers. As he commented in one of his interviews:

T: I don't make a major issue out of [the quizzes], because you know, I basically when I get done discussing material and they've worked a few problems I give them a quiz just to really give them a feel more than me for whether they know it or not. So if they are given a quiz and there are, you know, three or four problems on the quiz and they can't work any of them that should be a pretty good clue that, you know, you've got a problem and either need extra help or need to do a little extra studying. (PTI STO 648)

There are three comments to make about this analysis of Fielder's system from the students' perspective. First, while there was the potential for students to express their own views at various points in the system, it seems clear that there was no incentive for them to do so: the only thing valued was the right answer and the only point of interest in other answers was how close they were to the right answer.

Second, there was a considerable discrepancy with respect to depth and detail between the objectives Fielder provided and the content of his lectures, in which he exhibited a very high degree of disciplinary knowledge. In his lectures he expanded in exhaustive detail on the topics in his curriculum, and he constantly made connections to previous concepts. The potential cognitive demand of these lectures was high. Yet while students were provided with many opportunities for understanding the material, they were not held accountable through testing for knowledge of the specific details or elaborate connections in his lectures. Test questions and problems were similar to those in the worksheets and assigned problems. A review worksheet that students completed before the test summarized the central themes of the topic.

Third, the actual cognitive demand of these explicitly stated objectives was not high. It is possible that students were able to get good grades through memorization of knowledge and comprehension of familiar problem types. There was little incentive, for example, for students to pursue the potential inherent in Fielder's well-crafted lectures. In summary, then, while there were opportunities for students to express their own views and the potential cognitive demand of the classroom content was high, the way in which Fielder used his system served to constrain these opportunities and reduce the cognitive demand in his classroom.

Conceptions. The analysis of Mr. Fielder's CTS interview shows that his conception of teaching science is predominantly student-centered. Two of his three CTS themes are summarized as follows: he believes that his students should learn how to learn by being engaged in what they are doing.

Fielder's first theme is also his main goal in science teaching: Teaching students to think critically, to solve problems, to learn how to learn is more important than teaching them content knowledge. He believes that learning skills need to be the focus of classroom activities; these include reading, analyzing, solving problems, experimentation, and organization in terms of taking tests, listening to lectures, and taking notes.

His second theme is closely related to the first. Student engagement is the most central element in any attempt to facilitate learning. He looks for engagement in experiments, in questioning, and in listening, and thinks that one of the best ways for students to learn is to interact with each other and discuss things. He also believes that students' knowledge background and the teacher's ability to provide feedback appropriate to this background influence what they can learn.

Discussion. The student-centered nature of Mr. Fielder's CTS themes--learning how to learn, student engagement--appears to be directly at odds with a classroom that was built around lengthy, involved lectures and recitation of assignment answers. In particular the analysis of Fielder's system showing that he did not use it to track students' views seems to contradict his statement about the importance of a teacher's ability to provide feedback appropriate to a student's background. It is, however, useful to recognize the need to interpret Fielder's themes on his terms rather than ours. Learning how to learn meant, for him, learning to perform the various tasks that formed his system: reading to find answers that met the objectives, listening to a lecture in order to take notes, solving the sort of textbook problems that appeared on the unit test, etc. He saw these as important tasks that required direct student involvement and engagement. In other words, within the constraints of meaning he imposed on these terms, these themes are reflected in his practices.

Fielder's interpretation of his CTS themes serves to reconcile the apparent discrepancy noted above between them and his teaching. It also, however, reveals what, in our view, is a very limited understanding of what is entailed in learning: if students are held accountable for clearly specified objectives, through frequent repetition of the desired answer they will learn. Such a view serves to justify a teacher-dominated classroom in which students' views have little importance. In other words, knowing the tasks Mr. Fielder requires of his students and understanding his views on learning and teaching--interpreted on his terms rather than ours--provides a very strong sense of what we might expect his students to learn in his classroom.

Discussion

The purpose of this article has been to consider the question: As a means of identifying student learning, what alternatives to testing exist within normal classroom practices? We have identified three alternatives that differ with respect to the increasing amount of interpretation required. These include:

- **Direct evidence.** Students provide feedback in a number of different forms other than writing tests and examinations. These forms do, however, differ with respect to the explicitness of the evidence.
- **Tasks and tools.** The tasks that teachers require students to perform and the tools they provide for their students to use provide information on the opportunities for and the constraints on the potential for student learning. Two ways in which tasks and tools differ are with respect to their potential for providing direct evidence, and the level of cognitive demand required to complete or use them.
- **Teacher conceptions.** The conceptions that teachers hold about teaching science appear to play a part in the decisions they make to use certain sorts of tasks in preference to others. The conceptions of both of the teachers illustrated above provided significant insight into the ways in which these teachers interpreted the tasks they used in their teaching.

The detailed illustrations of the two teachers presented above demonstrate, in our view, that knowing the tasks and tools that they used and the conceptions they held about teaching science can provide a great deal of information about the type of learning one might expect to occur in their classrooms. The information is, of course, about the class rather than about individuals: we cannot say anything about what Maria or Jimmy actually learned. It is also somewhat general: it refers to probable ranges of learning outcomes that are either included or excluded. Finally, it depends on a good deal of interpretation. In spite of these evident shortcomings we believe that with this information we know significantly more about potential student learning outcomes in these two classrooms than without it. At a time when there is a rapidly growing interest in alternative forms of assessment, e.g., portfolios, we believe that investing time, effort, and interest in tasks, tools, and teacher conceptions will pay dividends in understanding and improving teaching and learning in science.

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